Magnetic Behavior and Phase Transitions of Selected Pure, Dilute and Mixed Magnets

Gary C. DeFotis, College of William and Mary, DMR-0085662

Magnetism in one form or another is a near universal facet of nature. It is also one of the most practical, with myriad applications of which perhaps the most widespread is recording technology. Great variety is also evident in magnetic phenomena at the fundamental level. Much of our work has been concerned with phase transitions in mixed magnetic insulating materials. Although binary mixtures have been the rule, we decided that a ternary mixed magnetic insulator should be examined. For this purpose $Co_{1-x}Mn_yFe_{x-y}Cl_2{\bullet}2H_2O$ is a near optimal choice. The three components mix well and each of the binary combinations has been well studied, with contrasting behavior. The mixture of $FeCl_2{\bullet}2H_2O$ and $CoCl_2{\bullet}2H_2O$ has competing orthogonal spin anisotropies; the mixture of Co and Mn components has competing ferromagnetic and antiferromagnetic exchange interactions; and the mixture of Fe and Mn components has both the above types of competition. The latter two combinations were first studied in our laboratory, the first by Katsumata in Japan. We have prepared a series of ternary mixtures chosen so that a reasonable sampling of composition space is achieved based on a manageable number of (x,y) values. Shown in the figure are two sets of susceptibility data for two compositions. Contrasting features are the quite different locations where susceptibility maxima occur and the different low temperature behavior, with one mixture displaying a monotonically decreasing susceptibility and the other an upturn with structure. Much other data has been collected, on many different mixtures, to explore the global temperature-composition phase diagram and to study magnetic irreversibility effects. This is the first insulating ternary magnetic system ever examined in such fashion.

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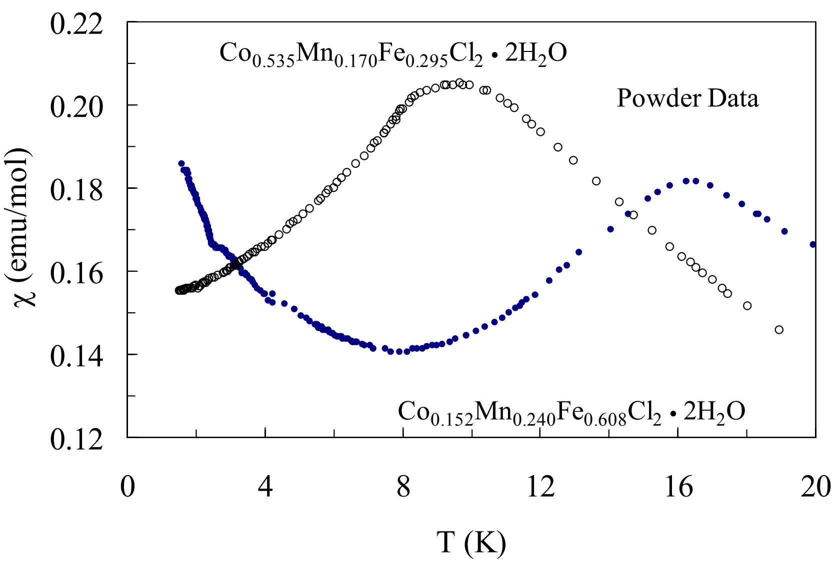

Molar magnetic susceptibility vs temperature for two ternary compositions. Open symbols are for upper formula.

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Education:

Three students did senior research and either graduated or soon will: Richard Huddleston, Mary Kim and Benjamin Rothermel. Mary also wrote a thesis, defended it before a committee, and will graduate (Dec.) with honors. Three continuing students, Jonathan Boyle, Zachary Reed and Erica Vos, completed their Introduction to Research course with the PI and did research here in summer 2004. Daniel Chan joined our group later and also did summer research.

International and Other Collaborations:

Our collaboration with Professor Fernando Palacio (Univ. Zaragoza) for neutron studies of deuterated $Fe[S_2CN(C_2D_5)_2]_2C1$ remains in place; beam line problems at the ILL have held up work to date. An international collaboration with Dirk Visser of the Rutherford Appleton Laboratory is also underway, for muon and neutron work on the $MCl_2{\bullet}H_2O$ series we developed, and for which deuterated material is being prepared. Collaborations for high field magnetization, neutron and heat capacity measurements on many other systems are also agreed to with Professors Mark Meisel (Univ. Florida) and David Belanger (Univ. Cal., Santa Cruz.)

Outreach:

The PI will again (October 2004) present a talk to a general audience at the William and Mary Homecoming Academic Festival, "Examining Exotic Magnets: Why Esoteric Research is Important". Commercial and societal applications of magnetism are presented, as is the philosophy which drives scientific discovery, intentional as well as serendipitous. A viewframe from the talk appears below.

Why pursue basic, often esoteric, research?

1. Advances in knowledge and understanding
   a. because it is a good in itself
   b. because it is enjoyable
   c. because future technological progress depends on it
2. There can be negative side effects of technological progress, but usually not necessarily so. Nor are scientists typically the ones who decide how new knowledge is put to use. Also, if one fears side effects one should say what one would be willing to do without.
3. Much basic research is done in academe, in the service of education. Future scientists need to understand much that is basic before making contributions to applications.
4. Much less basic research is done in industry than formerly. Short-term, bottom-line considerations dominate. Hence, basic research done in academe is correspondingly more important.
5. No one can predict what will or will not eventually be useful, nor the side effects. Therefore, it is impossible to restrict research only to that which will be (self-evidently) useful. A 19th century example: An important politician (possibly Gladstone) visited the Royal Institution in London to witness Faraday's electrical novelties. The politician is reported to have said, "Very amusing, Mr. Faraday, but what is the use of it?" To which Faraday replied, "What is the use of a new-born babe? In any case, you will one day put a tax on it."

Who: Gary C. DeFotis (PI) and international collaborators
Fernando Palacio and Carlos Beccera

Where: College of William and Mary, Williamsburg, VA
Univ. Zaragoza, Spain
Univ. Sao Paulo, Brazil

What: Heat capacity measurements demonstrating the lack of magnetic ordering to unexpectedly low temperatures in a recently developed mixed magnet. Magnet field dependent ac susceptibility measurements on an unusual five-coordinate molecular ferromagnet, demonstrating the existence of critical fluctuations above the transition, and their adherence to scaling theory predictions.

So What: Both examples are exceptionally novel magnetic systems with detailed behavior that is in certain respects unique: the phase diagram of the Co/Mn system, and the apparent chiral model behavior of the Fe compound.